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INFLUENCES OF TEMPERATURE AND PRESSURE TO THE GREEN DEFECTS

Tan Koon Tatt
Faculty of Engineering & Information Technology, MAHSA University,
Bandar Saujana Putra, 42610 Jenjarom, Selangor. Malaysia

NorhamidiMuhamad, Che Hassan CheHaron and Abu BakarSulong
Department of Mechanical and Material Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

ABSTRACT

Metal injection moulding has been recognised as a useful technique to produce the parts with high complexity. In this study, an experimental run was carried out to identify the influence of injections parameters on the green defects. The parameters investigated are injection temperature, injection pressure and mould temperature. Experimental tests were conducted on water atomised stainless steel feedstock with 62 vol% powder. Multi-component binder consisting PEG, PMMA and strearic acid were used. The standardise tensile-test specimen were injection moulded by varying the injections parameters. Injection moulding was carried out at temperatures and pressures of 140–160°C and 550–750 bar respectively. The feedstocks prepared exhibit pseudo-plastic behaviour. The experimental results showed that the flashing and binder separations are the major defects. These defects are caused by the high injection temperature and high injection pressure. At the low mould temperature, the defects such as distortions and cracking were observed. From the surface defects point of view, the injection temperature of 150 °C, the mould temperature of 70 °C and injection pressure of 550 bars seem to be the most suitable condition for injection moulding.

Keywords: Metal injection moulding, injection temperature, injection pressure, mould temperature, green defects.

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1. INTRODUCTION

Metal injection moulding (MIM) is a combination technology of powder metallurgy and plastic injection moulding. It is known to be very attractive as it can produce complex and near net shape product with low cost. This technology consists of four significant steps namely a mixing, injection, debinding and sintering. Recently, considerable attention has been given to the processing parameter since the success of MIM is solely depending on the orientations of parameters [3], [4], [17]. The injection moulded parts are called the green body. The moulding parameters of MIM are different from plastic injection moulding due to its rheological and thermal behaviour [1]. The essential injection parameters include injection temperature, mould temperature, injection pressure, holding pressure, injection speed, injection time and cooling time. Injection temperature and injection pressure are the most crucial injection parameter in determining the success of the MIM process [1], [12].

Generally, the injection temperature for the MIM process is less than plastic injection moulding. The injection temperature is usually the same as the melting temperature of the binder. Low injection temperature is avoided as pre-freezing of feedstock may occur in the barrel. It will not only lower the production rate but also damage the barrel. High injection temperature also not used in MIM process due to the low viscosity of binder may cause flashing. Once the feedstock was injected into the mould, the cooling of the part will start. The mould has to heat up to a certain temperature to prevent the rapid cooling. Rapid cooling will generate the internal stress on the part and cause the cracks. The mould temperature varies from 20^{o}C to 100^{o}C depending on the type of metal powder, and binder used[1], [12].

Other green defects which associate with temperature and pressure includes short shot, slumping, weld lines, sink mark, silver steak and internal voids. The short shot is a fatal defect where subsequent operation on parts cannot be done. Low injection temperature and low injection pressure are the primary cause of the short sort [1], [10]. Low injection pressure and temperature may also cause sink mark [4]. Weld lines are formed when two flow fronts are merged. To avoid weld lines, injections temperature and mould temperature must be sufficient [4], [7]. However, the injection pressure cannot be too high as it may result in flashing defect [4], [7]. Silver steak and internal voids are mainly deal with the injection pressure whereas the low viscosity of feedstock causes slumping.

Injection is a crucial and vital step in the MIM process. Improper monitoring of the injection moulding process will lead to the low quality of MIM parts. Thus, this paper is aim to investigate the green defects that occur during injection moulding in the MIM process. The influences of the injection temperature, mould temperature and injection to the green defects were studies. Besides, the optimal injection conditions based on the green part surface defect also determined.

2. EXPERIMENTAL PROCEDURES

The metal powder used in this study is the water atomised 316L stainless steel powder with particle size D_{50} = 10μm and spherical in shape. The solid loading is 62% vol with binder used consisted of Polyethylene glycol (PEG) (73% wt), Polymethyl methacrylate (PMMA) (25% wt) and stearic acid (2% wt). The details of the solid loading of feedstock are shown in Table 1.

The stainless steel powders were mixed with binders in a z blade mixer for 1 hour and 35 minutes at 70^{o}C. The mixture is then granulated into pallet form through crushing machine. Prior to the injections, rheology test was conducted by Shimadzu CFT-500D.The tensile-test specimens are injection moulded using a Battenfeld BA 250CDC injection moulding machine. The injections were carried out by varying the temperature and pressure while

keeping the others parameter constant. The operating temperature and pressure range are determined via feedstocks' rheological behaviour and preliminary run.

Table 1 Solid loading of feedstocks

Component		Vol (%)	Wt (%)	Wt (%)
Powder	Water	62	91.64	100
	atomised			
	SS316L			
	PEG		6.10	73
Binder	PMMA	38	2.09	25
	Stearic Acid		0.17	2

3. RESULTS AND DISCUSSIONS

3.1. Determination of moulding condition via rheological behaviour and preliminary run

The viscosity of MIM feeds tocksis characterised as temperature-dependance. In MIM, feedstocks with shear thinning or pseudo-plastic behaviour are desired [2], [10], [14], [19], [20]. The MIM feedstocks with pseudo-plastic behaviour have the value of flow behavior index, *n*less than one [2], [10], [14], [15], [19], [20]. Pseudoplastic behaviour eases mould filling, minimising jetting and help to retain the shape of the moulded part. According to the literature [2], [14], [15], the desired MIM feedstock have a shear rate between 100 to 10000 s^{-1} and its viscosity falls below 1000 Pa.s. Table 2 and Table 3 shows the results obtained from the rheology test. From Table 2, it can be seen that the load above 100kgf/cm^2causing the shear rate to decrease and viscosity increases. This evidence suggests that high injection pressure may cause binder separation which will increase the viscosity of the feedstock near the gate.

Results from Table 2 indicate that the feedstocks used in this study exhibit pseudo-plastic behaviour. With the$n$<1and majorityshear rate and viscosity fall within the desired range, it can be concluded that the feedstock prepared are suitable for injection moulding. However, the preliminary runs have shown the injection temperature of 130^{o}C is not suitable as pre-freezing of feedstocks occur. Thus, the injection temperatures used vary between 140^{o}C to 150^{o}C. The moulding condition for injection moulded specimen as illustrated in Table 4.

Table 2 Rheological data for the feedstock

Temperature (^oC)	Load (kgf/cm^2)	Shear rate (s^{-1})	Viscosity (Pa.s)
130	80	428.5	400.7
	90	424.8	786.7
	100	278.6	1042.3
	110	211.4	6414.7
	120	26.9	11245.7
140	80	360.8	618
	90	488.8	810.4
	100	243.0	1249.3
	110	97.7	6602.3
	120	56.6	7540.7
150	80	536.5	422.6
	90	464.0	427.5
	100	285.9	944.9
	110	161.5	1781.1
	120	46.7	8233.7

Table 3 Flow behaviour index of the feedstock at the different temperature

Temperature (^oC)	Flow behaviour index, *n*
130	0.3235
140	0.2641
150	0.1988

Table 4 Moulding Condition

Parameters	Range
Injection temperature	(140, 150, 160) ^oC
Mould Temperature	(60, 65, 70) ^oC
Injection pressure	(550, 650, 750) bar
Injection speed	15, $cm^{3/}s$
Holding pressure	1000 bar
Holding time	15 s
Cooling time	15s

3.2. Influences of injection parameter to the green defects

All specimens in this study were injected without the short shot. Figures 1to Figure 3 are the green defects observed during the injection moulding. Green broken was found at the injection temperature of 140^{o}C and 160^{o}C.At 140^{o}C, the feedstock is viscous whereas 160^{o}C the green parts were soft due to the short cooling time. The soft green parts not only contribute to green broken, but it also causes the ejector mark (Figure 2(a)) and deflection (Figure 2(b)). Chipping is another minor defect noticed during injections temperature of 150^{o}C. Binder separation as shown in Figure 1(c) was found at 160^{o}C. Binder separation occurs at high injection temperature and high injection pressure [12], [13]. During the high injection temperature, the binder becomes less viscous causes it separates out from the

feedstock. The low viscosity of the binder at high injection temperature also causes flashing [4], [12], [13].

Mould temperature used in this study between $60^{o}C$ to $70^{o}C$. The green defects associate with injection temperature also affected by mould temperature. For instance, deflections and ejector mark were found at a high mould temperature. Also, at the combination of high mould temperature: 70 ^{o}C and high injection temperature: 160 ^{o}C results in severe flashing and binder separations. Figure 2(c) shows part was injection moulded at the mould temperature of 60 ^{o}C. It indicates that low mould temperature is not suitable for injection moulding because low mould temperature leads to the rapid cooling and generate internal stress in the green part. High-temperature gradient and internal stress cause cracks on the green parts [1], [4], [13]. The crack was found lesser when mould temperature increase to 65 ^{o}C and 70 ^{o}C. It can be concluded that the injection temperature of $150^{o}C$ and a mould temperature of $70^{o}C$ were found to be the best condition to injection moulded.

Figure 1 Green defects observed: (a) green broken, (b) chipping at the gate, and (c) binder separation

(a) (b) (c)

Figure 2 Green defects observed: (a) flashing and ejector mark, (b) deflections, and (c) cracking

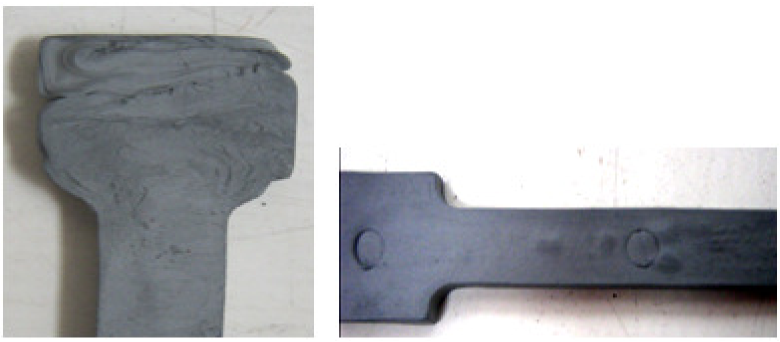

Figure 3 Green defects observed: (a) wrinkle, and (b) silver steak

Two major defects caused by injections pressure were flashing and binder separations. The similar results were obtained in the study conducted by Murtadhahadi [12] and Norhamidi et al. [13].Flashing was observed at high injection pressure: 750 bar whereas binder separations occur at 650 bar and 750 bar. Koffi et al. [6] and Wahi et al. [10] reported

excessive material is squeezing out of the mould when the part is injection moulded with high pressure. Excess binder separations were found when the parts injection moulded at high temperature and high pressure.

Moreover, injection at high pressure: 750 bar may bringto another two defects as shown in Figure 3(a) and 3(b). Wrinkle was noticed occur along the gate position.It can be explained by the viscosity difference between the binder and metal powder when injection pressure increases. In high injection pressure, binders which less viscous were force into inner part while viscous metal powder generates wrinkle along gate position. Injection at 750bar causes the air trapped in the green part as shown in Figure 3(b). The most suitable injection pressure used for the feedstock in this study is 550 bar as aminor defect were found.

4. CONCLUSION

From the experiment conducted, the following can be concluded in the present study:

- Injection temperature 150 OC, mould temperature 70 OC and injection pressure 550 bar are the optimal condition for feedstocks in this study.
- Injection temperature 130 OC can cause pre-feezing of feedstock to occur in barrel whereas high injection temperature causes flashing, binder separations, green broken, ejector mark and deflections.
- Cracking occurs at low mould temperature due to rapid cooling of the green parts.
- High injection pressure may cause flashing, binder separations, wrinkle and silver steak.

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